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PRESSURE AND NORMAL-FORCE DISTRIBUTIONS ON TOMAHAWK AND SANDHAWK MODELS AT MACH NUMBERS 6 AND 8

J. D. Magnan, Jr.

ARO, Inc.

June 1967

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PRESSURE AND NORMAL-FORCE DISTRIBUTIONS ON TOMAHAWK AND SANDHAWK MODELS AT MACH NUMBERS 6 AND 8

J. D. Magnan, Jr.
ARO, Inc.

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FOREWORD

The work reported herein was done at the request of the Sandia Corporation under Program Area 921D.

Sandia Corporation Contract 6007/003
Buyer: J. G. Boyes, 2523
Requester: O. L. George, Jr., 9322

The results of tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. The test was conducted from February 21 to 23, 1967, under ARO Project No. VB1761, and the manuscript was submitted for publication on April 26, 1967.

This technical report has been reviewed and is approved.

James N. McCready Major, USAF AF Representative, VKF Directorate of Test	Leonard T. Glaser Colonel, USAF Director of Test

ABSTRACT

Wind tunnel tests were conducted at Mach numbers of 6 and 8 to obtain pressure and normal-force distribution data on the Tomahawk and Sandhawk configurations. Model angle of attack ranged from -4 to +6 deg at free-stream Reynolds numbers, based on model diameter, of 0.43×10^6 and 0.73×10^6 at Mach number 6 and 0.43×10^6 and 0.58×10^6 at Mach number 8. Selected results are presented to illustrate the types and quality of data obtained.

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NOMENCLATURE

a	Area per unit length, in.
C_{N_x}	Unit normal-force coefficient (see Section 3.2), in.$^{-1}$
C_p	Pressure coefficient, $(p - p_\infty)/q_\infty$
j	Number of pressure orifices in one quadrant at any model station
M	Mach number
p	Pressure, psia
q	Dynamic pressure, psia
Re	Unit Reynolds number, ft^{-1}
r	Local model radius, in.
S	Maximum model cross sectional area, 3.142 in.^{2}
T	Temperature, °R
x	Axial distance from virtual apex of model, in.
α	Angle of attack, deg

SUBSCRIPTS

D	Reynolds number based upon 2.000 in. (maximum model diameter)
i	Pressure orifice number at any model station
ℓ	Conditions on the lower surface of model
o	Tunnel stilling chamber conditions
u	Conditions on the upper surface of model
∞	Free-stream conditions

SECTION I
INTRODUCTION

A study is being made by the Sandia Corporation to evaluate the effect of aeroelasticity on the static and dynamic stability of a rocket vehicle. The purpose of the test described in this report was to provide pressure and normal-force distribution data to be used in a computer program which evaluates the structural bending of a rocket body. The configuration was a scale model of the Tomahawk vehicle with fins which could be changed to simulate the Sandhawk vehicle. Model angle of attack was varied from -4 to +6 deg at Reynolds numbers, based on model diameter, of 0.43×10^6 and 0.73×10^6 at Mach number 6 and 0.43×10^6 and 0.58×10^6 at Mach number 8.

SECTION II
APPARATUS

2.1 MODELS AND SUPPORT EQUIPMENT

The model (Figs. 1 and 2) was furnished by the Sandia Corporation. It was a slightly blunted tangent-ogive cylinder of 47.073-in. overall length and 2-in. diameter with fins mounted on the downstream end. There were two sets of fins: one for the Tomahawk configuration and the other for the Sandhawk configuration. The model body was constructed of 42-percent nickel-iron alloy, and the fins were made of stainless steel.

The model was instrumented with 0.042-in.-diam orifices at 16 different model stations (Fig. 2a). Each station had a set of orifices in one quadrant on the upper half of the model and one quadrant on the lower half of the model (Fig. 2b). Model temperatures were monitored by six thermocouples, three on the upper half of the model and three on the lower half, to assure a temperature differential of less than 25 deg between the windward and leeward sides of the model to minimize warpage caused by differential heating.

2.2 WIND TUNNEL

Tunnel B is a continuous, closed-circuit, variable density wind tunnel with an axisymmetric contoured nozzle and a 50-in.-diam test

section. The tunnel operates at a nominal Mach number of 6 or 8 at stagnation pressures from 20 to 250 and from 50 to 900 psia, respectively, at stagnation temperatures up to 1350°R. The model may be injected into the tunnel for a test run and then retracted for model cooling or model changes without interrupting the tunnel flow. A description of the tunnel may be found in the Test Facilities Handbook[1].

2.3 INSTRUMENTATION

Model pressures were measured with 15-psid transducers referenced to a near vacuum. From repeat calibrations, the estimated measurement precision was ±0.003 psia or ±0.5 percent, whichever was greater. Model flow field schlieren photographs were obtained during selected tests. Figure 3 shows a typical photograph of the flow over the forward portion of the model.

SECTION III
PROCEDURE

3.1 TEST CONDITIONS

A summary of the combinations of tunnel conditions, model configurations, and model attitudes is given in Table I. The tests were

TABLE I
TEST CONDITIONS

Configuration	M_∞	$Re_\infty \times 10^{-6}$ ft^{-1}	p_o, psia	T_o, °R	p_∞, psia	q_∞, psia	α, deg
Tomahawk	6.03	2.6	145	850	0.089	2.27	0, 2, 4, 6
	6.05	4.4	250	850	0.150	3.86	-4, 0, 2, 4, 6
	7.98	2.6	575	1310	0.060	2.67	0, 2, 4, 6
	8.01	3.5	800	1335	0.081	3.65	0, 2, 4, 6
Sandhawk	6.03	2.6	145	850	0.089	2.27	-4, 0, 2, 4, 6
	6.05	4.4	250	850	0.150	3.86	-4, 0, 2, 4, 6
	7.98	2.6	575	1310	0.060	2.67	0, 2, 4, 6
	8.01	3.5	800	1335	0.081	3.65	0, 2, 4, 6

[1]Test Facilities Handbook (6th Edition). "von Kármán Gas Dynamics Facility, Vol. 4." Arnold Engineering Development Center, November 1966.

conducted at free-stream unit Reynolds numbers of 2.6×10^6 and 4.4×10^6 ft^{-1} at Mach number 6 and 2.6×10^6 and 3.5×10^6 ft^{-1} at Mach number 8 over a model angle-of-attack range of -4 to +6 deg.

3.2 DATA REDUCTION

The pressure orifices were located at 16 longitudinal model stations with the orifices at the first eight locations (from x = 0 to x = 36.000 in.) laid out on an equal projected area basis (see Fig. 2c). The unit normal-force coefficients for these model stations were computed from

$$C_{N_x} = \frac{1}{S} \sum_{i=1}^{j} \frac{2r}{j} \left(C_{p_{\ell_i}} - C_{p_{u_i}}\right)$$

At model stations of 41.291, 43.166, 43.916, and 44.666 in., the unit normal-force coefficient was calculated from the relation

$$C_{N_x} = \frac{1}{S} \sum_{i=1}^{3} 2a_i \left(C_{p_{\ell_i}} - C_{p_{u_i}}\right)$$

No normal-force calculations were made for model stations 40.166, 42.416, 45.416, and 46.166 in.

SECTION IV
RESULTS AND DISCUSSION

A plot of unit normal-force coefficient versus axial distance along the model at Mach number 7.98 and $Re_{\infty_D} = 0.43 \times 10^6$ is presented in Fig. 4 for various angles of attack. These distributions show an increase in unit normal-force coefficient with angle of attack with each distribution peaking at about x = 2 in. Figure 5 shows little Reynolds number effect on the Tomahawk model at Mach number 8 at 6-deg angle of attack.

The normal-force distributions on the Tomahawk configuration at 6-deg angle of attack (Reynolds number based on model diameter of 0.43×10^6) for variable Mach number are shown in Fig. 6. Normal-force coefficients at Mach number 6 ranged from 9 to 12 percent higher than those at Mach number 7.98 over most of the model length; the maximum deviation of approximately 30 percent occurred in the fin interaction region on the downstream end of the model.

Figure 7 gives a typical comparison of the normal-force distributions on Tomahawk and Sandhawk configurations at $M_\infty = 7.98$ and $Re_{\infty_D} = 0.43 \times 10^6$. The two configurations give identical data over all but the fin region from x = 40 to 45 in.

APPENDIX
ILLUSTRATIONS

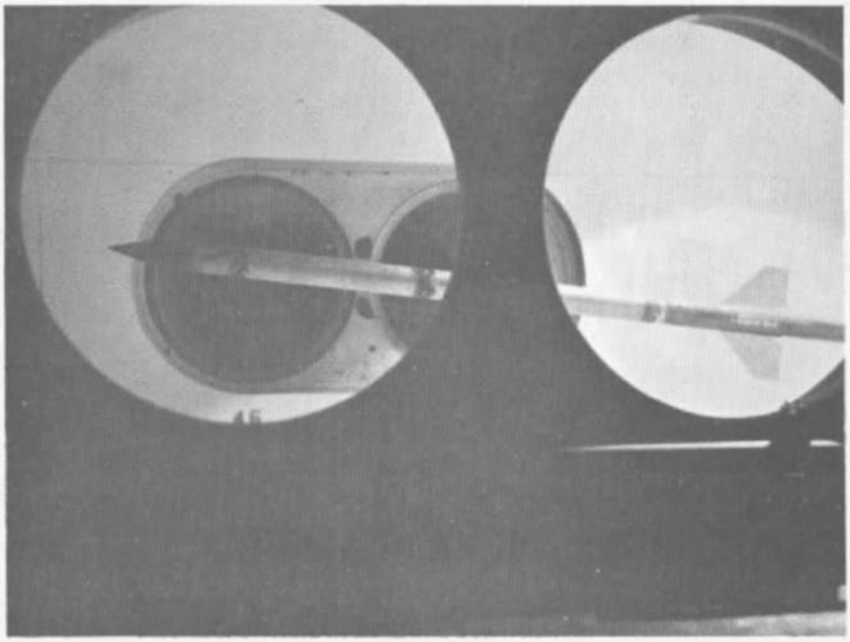
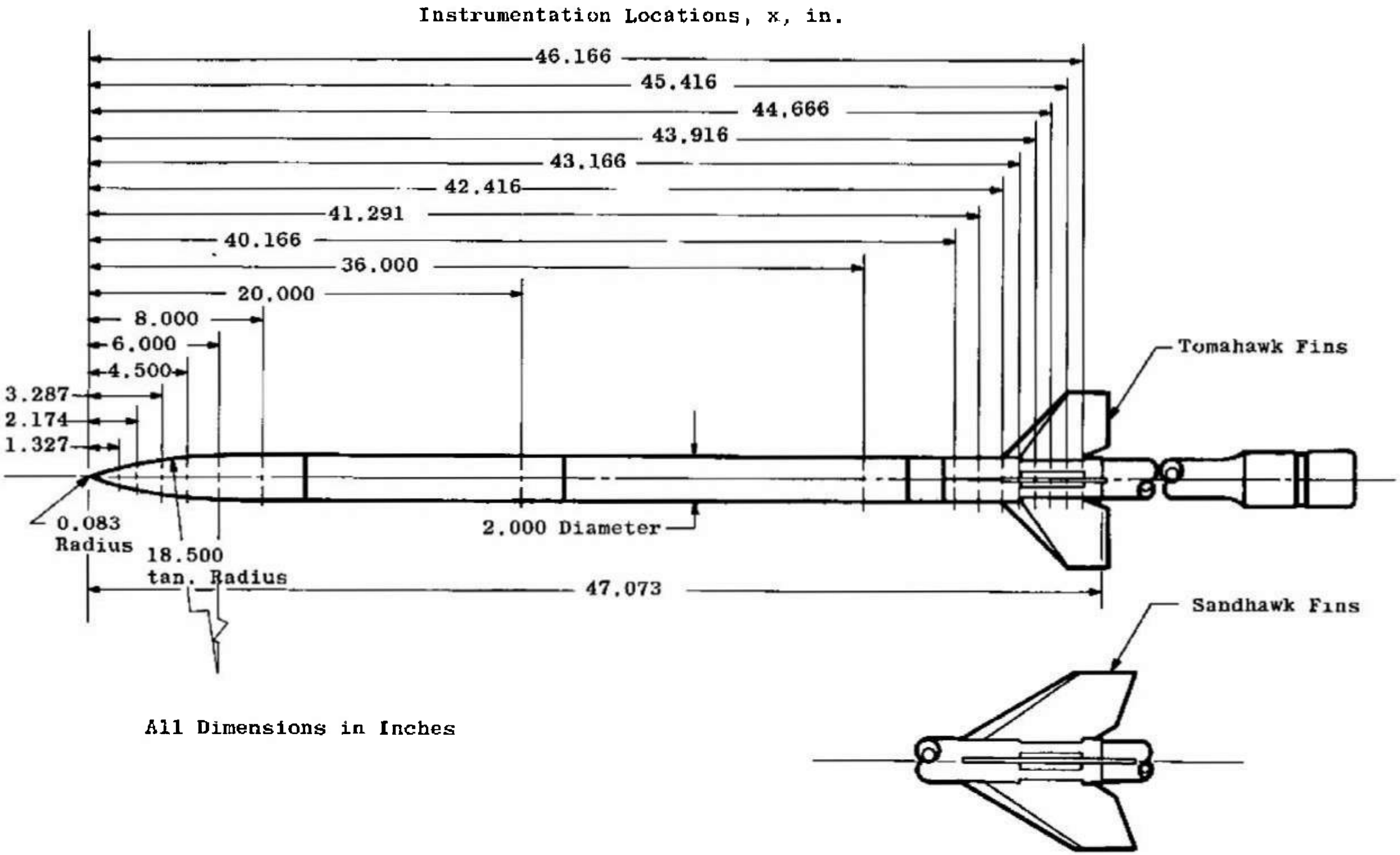
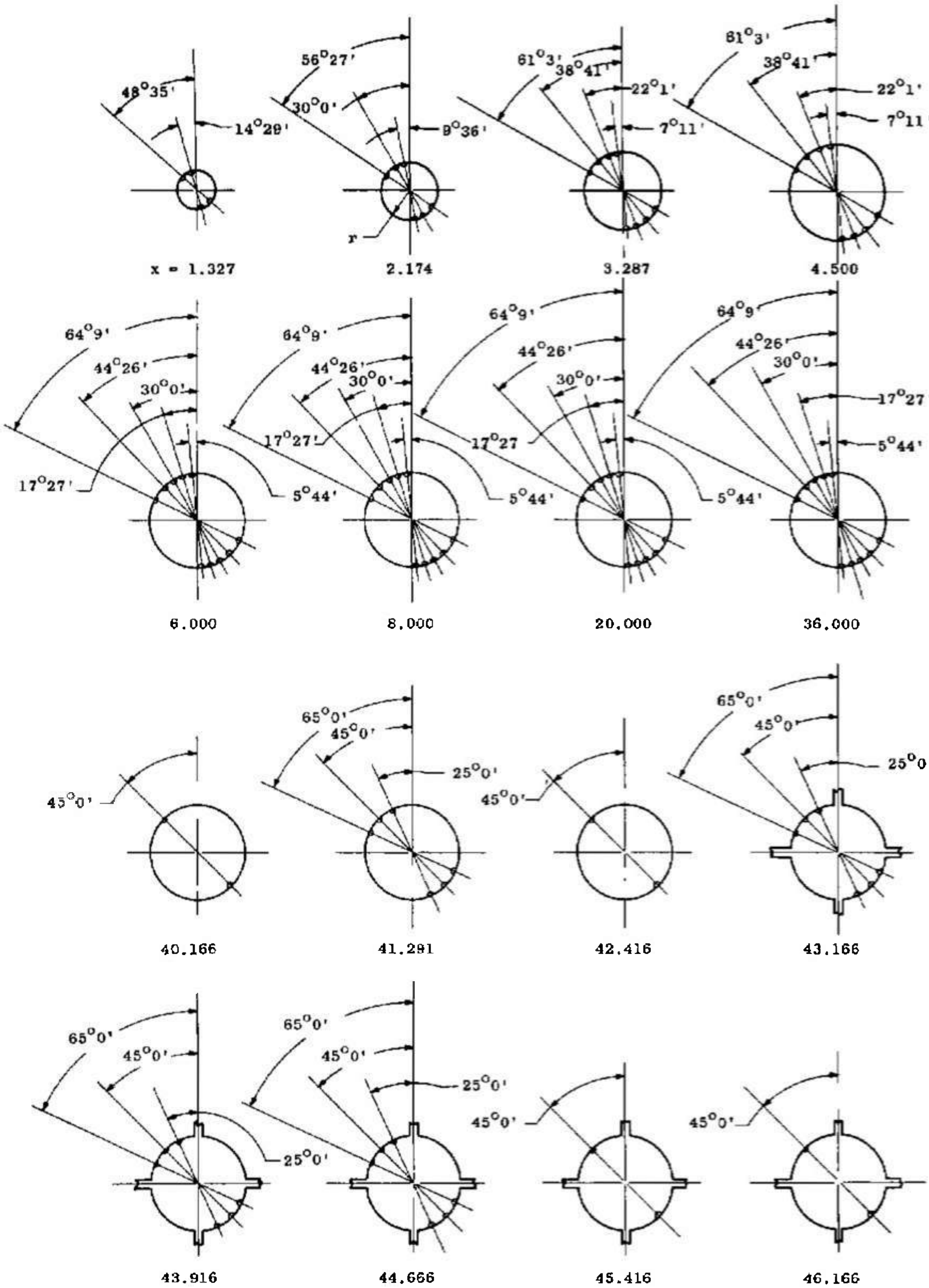


Fig. 1 Model Installation Photograph

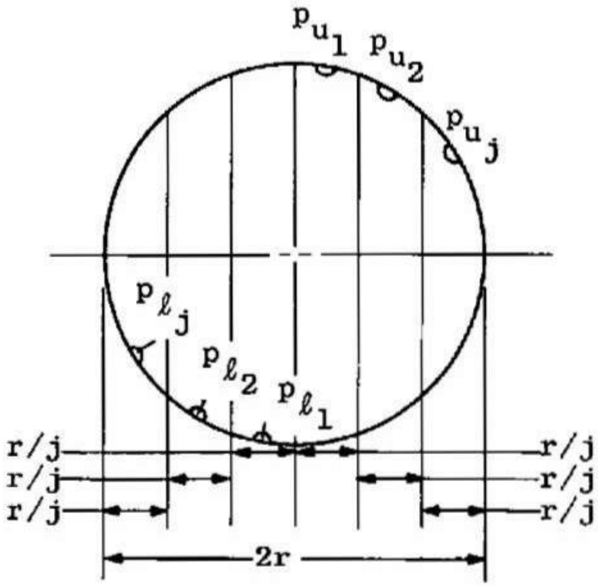


a. Model Details
Fig. 2 Model Details and Instrumentation

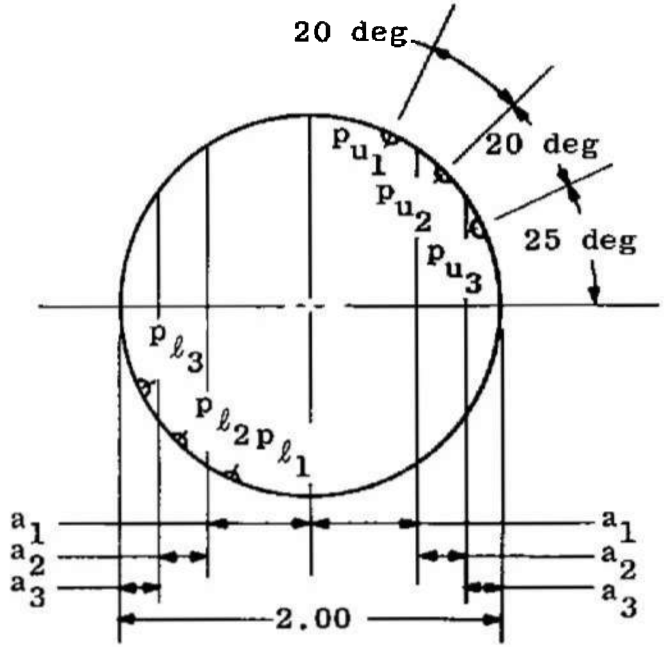


b. Model Instrumentation

Fig. 2 Continued



Orifice Layout for Instrumentation Locations x = 1.327 through 36.000 in.



Orifice Layout for Instrumentation Locations x = 41.291, 43.166, 43.916, and 44.666 in.

c. Pressure Orifice Layout

Fig. 2 Concluded

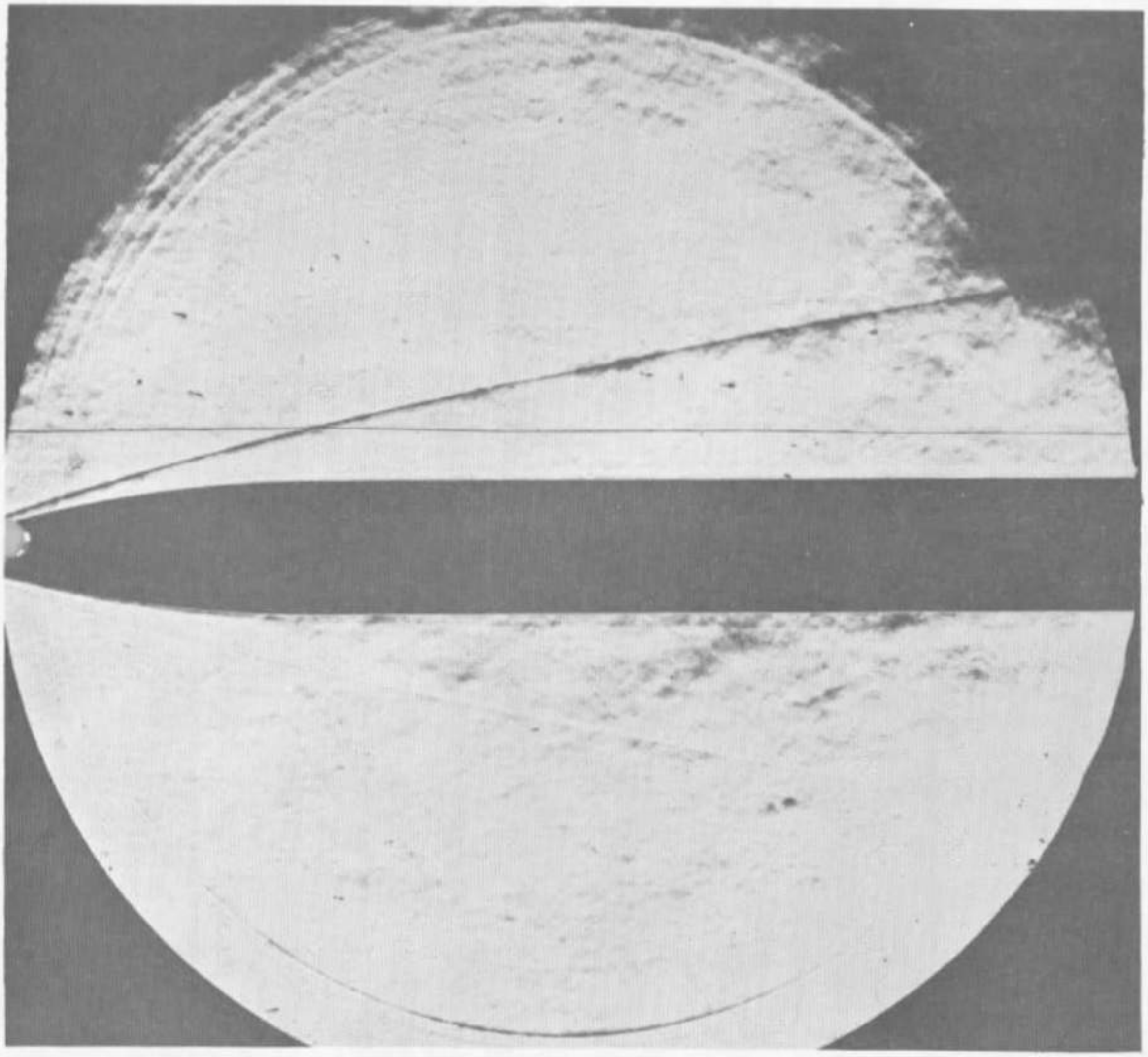


Fig. 3 Schlieren Photograph of Tomahawk Model at $\alpha = 0$, $Re_{\infty_D} = 0.43 \times 10^6$, $M_\infty = 7.98$

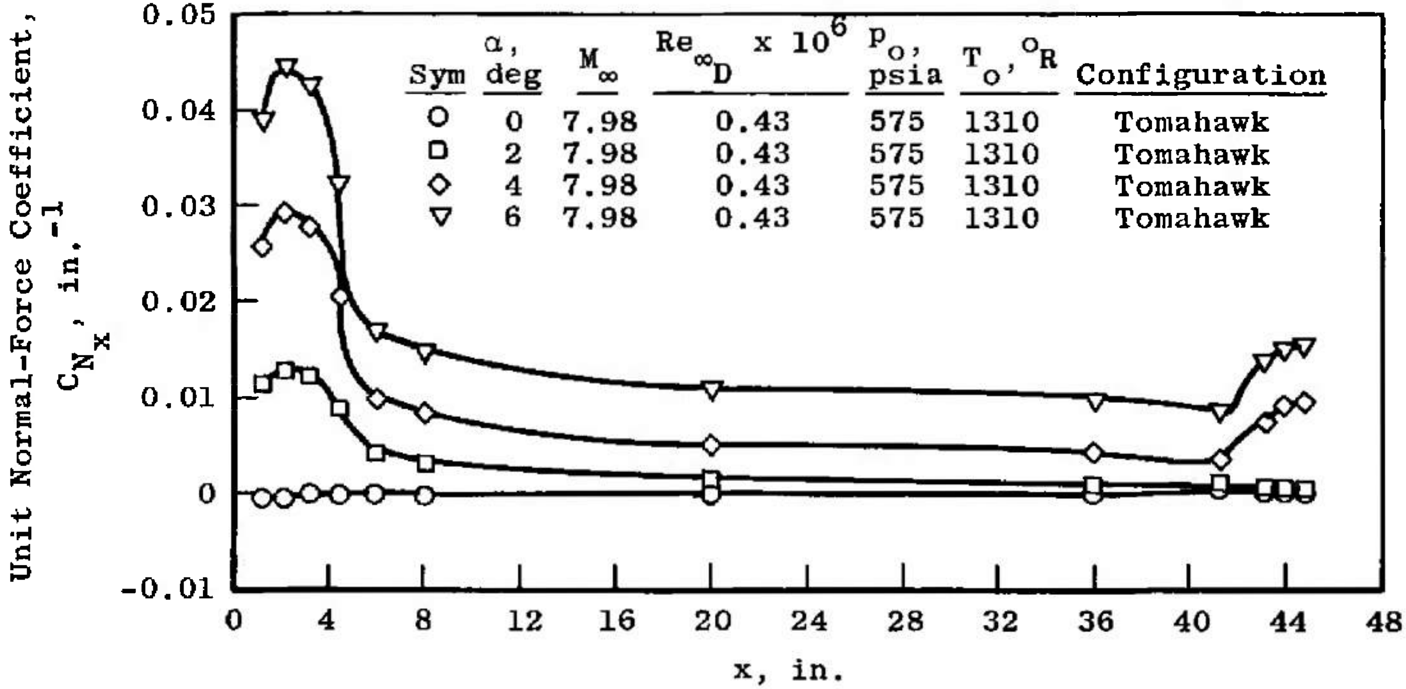


Fig. 4 Effect of Angle of Attack on Tomohawk Normal-Force Distribution

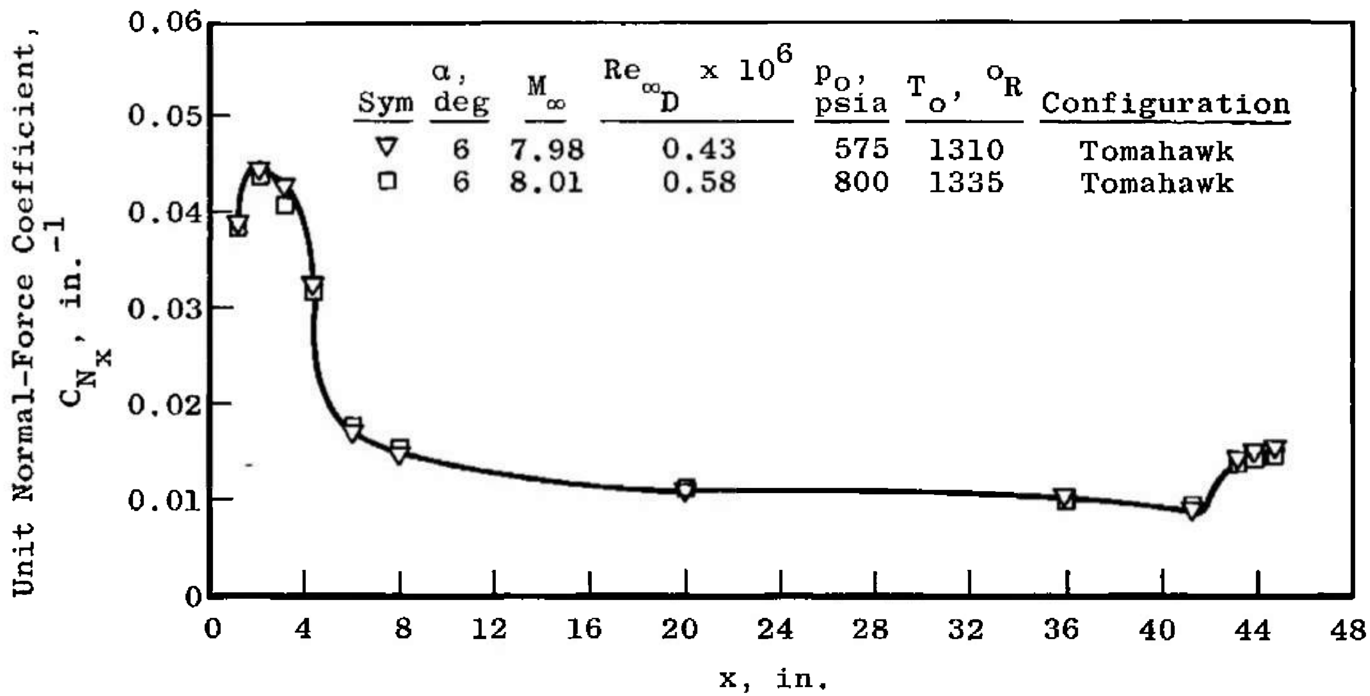


Fig. 5 Effect of Reynolds Number on Tomahawk Normal-Force Distribution

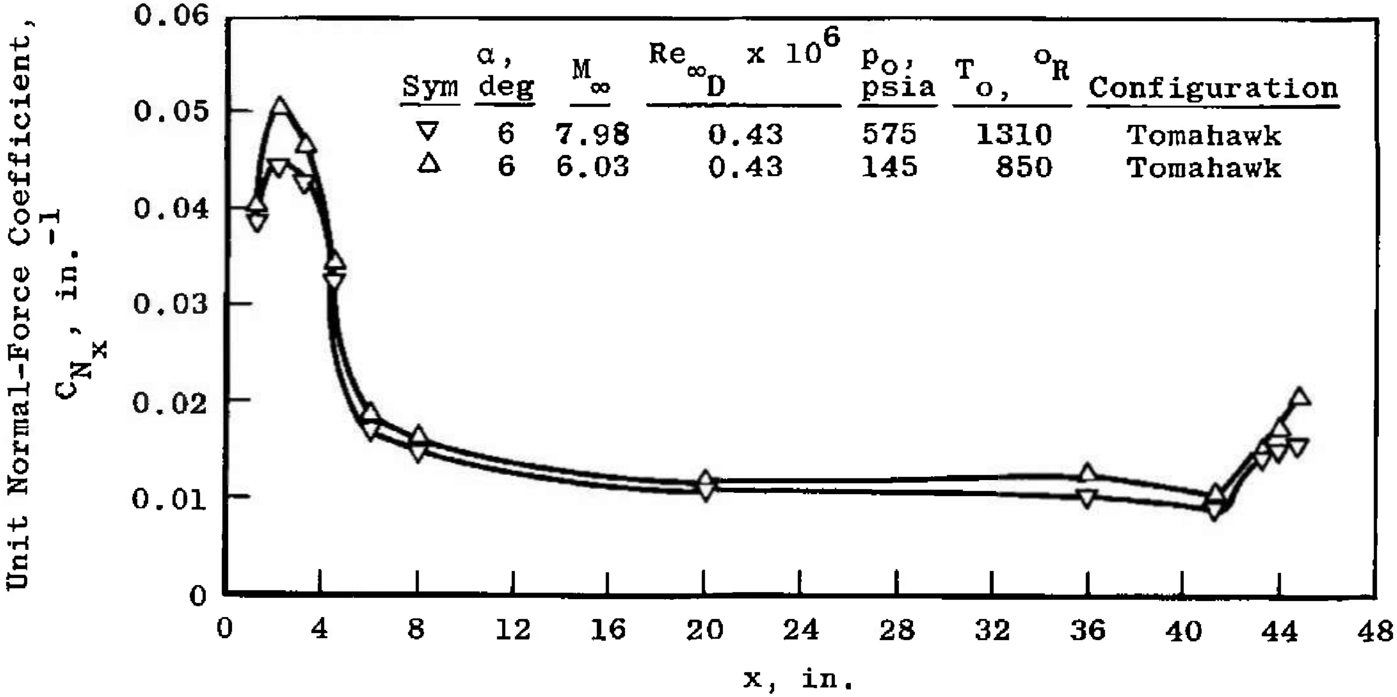


Fig. 6 Effect of Mach Number on Tomahawk Normal-Force Distribution

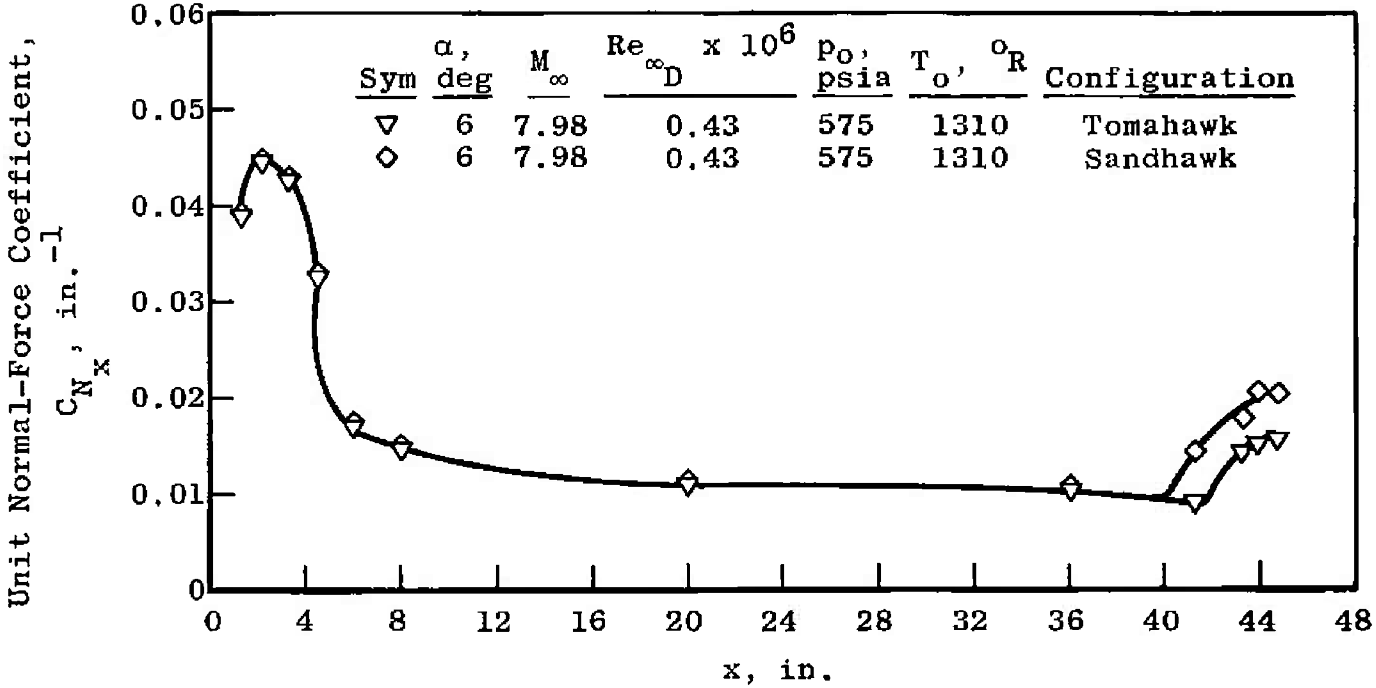


Fig. 7 Comparison of Tomahawk and Sandhawk Normal-Force Distributions

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1. Missiles - Tomahawk
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